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15. Supplementary Notes

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16. Abstract (MAXIMUM 200 WORDS)

This report describes the development of models used in the Navigation Aid Analysis Tool (NAAT), a self-contained software product that computes the probability of being in a given system state, most commonly, the incident state, for a user-constructed scenario of surface marine navigation in harbor entrance and approach navigation areas. The report describes error models of visual navigation systems, constructed so as to place them on an equal footing with other commonly used radionavigation systems. The report also traces the methods used to create a dynamic Markov state space model, necessary for determining incident rates for arbitrary input of user navigation systems, navigation areas, and vessel characteristics. For a given scenario, the computed incident rate may be compared to the target level of safety to determine if navigation requirements are met.

17. Key Words	18. Distribution Statement
Differential GPS, Loran-C, INS, IMU, GPS, Selective Availability, Visual Navigation, Visual Aids, Marine Radar, Incident Rate, Target Level of Safety, Markov Chain	This document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161

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Executive Summary

The USCG Research and Development Center is conducting the Aid Mix project to develop system analysis tools for the USCG Office of Aids to Navigation. A significant part of this research is to determine the performance of various combinations of navigational aids. In order to quantify the navigational performance in terms of safety, we have developed the Navigation Aid Analysis Tool (NAAT). The objective of this report is to describe the theoretical structure and models underlying NAAT. NAAT is a software package, written and executed in MATLAB™, that calculates the probability of an incident (vessel grounding or collision with the edge of the channel) for a user-specified navigation scenario. The scenario includes data on the vessel characteristics, the navigation area through which the vessel is transiting, the navigation equipment on board the vessel and/or supporting infrastructure in the navigation area, and certain environmental conditions. The incident probability may be compared with a target level of safety (TLS) based on historical casualty rates or any other figure selected by the NAAT operator.

In addition to vessel size parameters and navigation area geography, NAAT input incorporates several navigational aids. Visual aids, Differential GPS, Loran, GPS, inertial navigation systems are included and the users can specify the characteristics of an additional aid to test any proposed systems. The user can edit the performance, selection and priority of any combination of these aids. When electronic aids are selected, the use of an electronic chart display system is automatically included. The user must assign relevant performance data to each navigational aid system. Performance data includes accuracy, mean time to failure and mean time to repair. The user can use the various navigation systems' actual values for these terms or potentially change them to investigate the effects of system improvements or operational doctrine changes. For example, the user could examine the effect of removal of GPS selective availability (improvement in GPS accuracy) on incident rate.

A key aspect of this work was the development of a visual navigation state to include short-range aids in a systematic fashion with radio-aids. Calculations for this state are based on two incident models: an empirical/statistical model invoked when any aids are visible, and a first-principles dead reckoning model for use in zero-visibility conditions. Another important development that makes this tool useful for studying arbitrary navigation areas and systems is the method devised to dynamically configure the Markov state space model for navigation incident probability. This means that the NAAT operator can construct and test his own scenarios rather than the fixed scenarios considered in earlier work. For the convenience of the NAAT operator, a vessel catalog

has been compiled and channel configurations have been constructed for the Tampa Bay and St. Mary's River navigation areas.

To increase its applicability and realism, the formerly one-dimensional model has been improved to include a two-dimensional turn sub-model based on smoothly continuous trajectory transitions between straight transit segments. The vessel control procedure assumed for turns is similar to the straight channel sections, i.e., the vessel is steered to the desired trackline/centerline, except that for turns, the trackline is assumed to be the arc of a circle with user-selectable length and pre-defined radius of curvature.

In conclusion, NAAT can be used to compare the relative safety margins for various combinations of primary/secondary navigation systems, different vessel types, and alternative navigation areas. NAAT can also be used to determine the relative safety of different portions of the navigation area. Another important application of NAAT is to examine the interrelationships between the TLS and critical navigation system parameters. This technique, referred to as sensitivity analysis, can be used to identify crucial parameters for any system and the effect of these parameters on system performance. NAAT is an important tool in analyzing the mix of aids-to-navigation provided by the Coast Guard. It forms the basis of the navigation performance analysis for the overall Aid Mix methodology. The next step in applying NAAT to the Aid Mix problem is to perform an independent verification and validation (IV&V). An IV&V will ensure that the NAAT implementation is as described and that NAAT provides valid information when used.